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DOUBLE-WALL PROJECTILE TARGET IMPACT SURVIVABILITY

by

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FOREWORD

This experimental study examines the survivability of double-wall projectiles under target impact. This work was performed during fiscal year 1983.

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(U) *Double-Wall Projectile Target Impact Survivability,* by O. E. R. Heimdahl, J. C. Schulz, and J. Pearson. China Lake, Calif., Naval Weapons Center, December 1983. 18 pp. (NWC TP 6495, publication UNCLASSIFIED.)

(U) Firings at normal incidence of small steel projectiles (one single-wall and two double-wall designs) were conducted against simulated concrete targets. The purpose of the firings was to examine the possibly deleterious effects of a double wall on warhead impact survivability. The results indicate that a double wall should not reduce survivability provided that it is not allowed to extend into the primary failure zone for the warhead.

CONTENTS

INTRODUCTION

Penetrator warheads for use against hard and moderately hard targets require relatively thick cases to withstand impact loads. Thicker cases, however, can result in poor fragmentation characteristics (fragments too large) when these same warheads are used in an air- or ground-burst mode. While multi-wall cases consisting of two or more concentric cylinders can provide greatly enhanced fragmentation (for the same overall wall thickness), there is concern that such cases may reduce survivability compared to monolithic cases

This experimental study examines the survivability of double-wall projectiles under target impact. Small hollow cylindrical steel projectiles (one single-wall and two double-wall designs) were fired at normal incidence against simulated concrete targets. Half the projectiles were filled with an explosive simulant, while the rest were left unfilled. Projectile impact velocities and penetration depths were measured. In addition, selected projectiles were cross-sectioned after test to reveal the deformation behavior of the double wall in more detail.

The projectiles used in the current tests were identical (except for the double wall) to projectiles used in previous experiments on the effects of shear-control grids on survivability.[1,2] On impact these latter projectiles tended to bulge near the front of the internal cavity and, at sufficiently high velocities, to fail in this region. A shear-control groove extending into the bulge region was found to reduce projectile survivability, while a groove outside this region had no effect. Based on these prior findings, it was felt that the location of the double wall in the present experiments might also be significant. Consequently, one double-wall projectile design had the double wall extending forward into the bulge region, while the other design had it starting to the rear of this region.

In this report the double-wall projectile experiments are described, the results are analyzed, and conclusions pertaining to the survivability of double-wall warheads are given. In particular, the importance of keeping the double-wall transition point outside the primary failure zone and the contribution of an explosive filler to stiffening the double-wall case are discussed.

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[1] Naval Weapons Center. *Survivability of Penetrators with Circumferential Shear-Control Grooves*, by J. C. Schulz and O. E. R. Heimdahl. China Lake, Calif., NWC, April 1981. (NWC TP 6275, publication UNCLASSIFIED.)

[2] -----. *Effect of Longitudinal Grooves on Survivability of Cylindrical Steel Projectiles Fired Against Simulated Concrete Targets*, by O. E. R. Heimdahl and J. C. Schulz. China Lake, Calif., NWC, November 1982. (NWC TP 6402, publication UNCLASSIFIED.)

DESCRIPTION OF EXPERIMENTS

PROJECTILES

The projectiles were flat-fronted steel cylinders, 2 inches long and 0.5 inch in diameter, each with a hemispherically-fronted internal cavity. The front of the cavity was 0.25 inch from the front end of the projectile, and the cavity wall thickness was 0.04 inch. In the double-wall designs the inner half of the thickness of the cavity wall was machined away and replaced by a sleeve such that, after assembly (with an interference fit of 0.001 inch), the total wall thickness was again 0.04 inch. The transition to double wall was either 0.46 or 0.71 inch from the front end of the projectile. The projectiles were machined from 4340 steel rods and were heat-treated (thus removing any residual stresses due to the interference fit) to a Rockwell "C" hardness of 38-40. The three projectile designs are shown in Figure 1.

FILLER

The internal cavities of half the projectiles were filled with plasticine (a wax-based modeling material), while the remainder were left unfilled. Plasticine is similar in density (1.6 g/cm^3) and consistency to some explosives and thus makes a reasonable explosive simulant.

TARGETS

The simulated concrete targets were made of Thorite (trademark of Standard Dry Wall Products), a fast-setting, high-strength (3950 psi compressive strength) concrete patching compound consisting of sand, cement, and additives to promote rapid curing. The largest sand grains are about 0.04 inch in diameter. The targets were cured for 7 days prior to the firings. Consistency in target preparation is critical for assuring high strength and uniformity among targets. The preparation procedure is described in the reference of Footnote 1.

TEST PROCEDURE

The projectiles were fired from a smooth-bore, 50-caliber powder gun and impacted the targets at normal incidence. The targets were placed about 18 inches from the end of the barrel. Impact velocities were measured in the gun barrel with a photo diode system coupled to an interval counter. The apparatus is described more fully by Goldsmith and Finnegan.[3]

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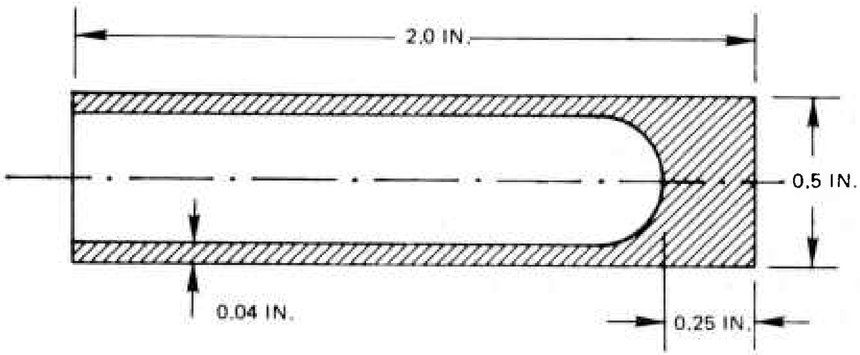
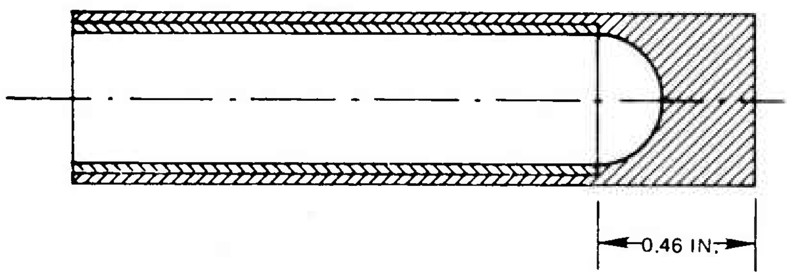
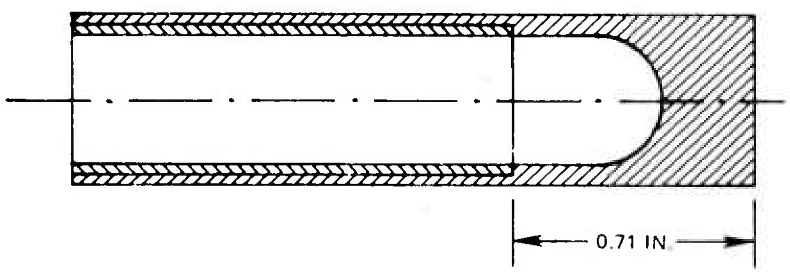
[3] W. Goldsmith and S. A. Finnegan. "Penetration and Perforation Processes in Metal Targets At and Above Ballistic Velocities," *Intl. J. Mech. Sci.*, Vol. 13 (1971), pp. 843-866.



(a) Single-wall.



(b) Double-wall starting at 0.46 inch from front end.



(c) Double-wall starting at 0.71 inch from front end.

FIGURE 1. Cross-sectional Views of Three Projectile Designs.

EXPERIMENTAL RESULTS

In all, 36 projectiles were fired: six unfilled and six filled for each of the three designs. Impact velocities ranged from about 1,600 to 2,600 ft/s. The results are summarized in Table 1. Penetration depth versus impact velocity is plotted in Figure 2. Also plotted are penetration curves based on the theory of Bernard and Creighton.[4] Except for projectiles that failed, these curves fit the data fairly well.

The chart in Figure 3 shows the impact behavior of the projectiles within the velocity range studied. The solid vertical lines denote projectiles that survived (bulged), while the dashed vertical lines denote projectiles that failed (fractured). The greyed areas indicate ranges of uncertainty for the survival velocity (defined as the velocity below which the projectiles survive and above which they fail). Bracketing values for projectile survival velocity are given in Table 2.

The appearance of the different projectile designs after impact near the upper velocity limit of their respective survival ranges is shown in Figures 4 through 6. Figure 4 shows unfilled and filled single-wall projectiles after impact at 2,495 and 2,410 ft/s, respectively. Figure 5 shows unfilled and filled projectiles with a double wall at the 0.46-inch location after impact at 1,960 and 2,230 ft/s. Figure 6 shows unfilled and filled projectiles with a double wall at the 0.71-inch location after impact at 2,285 and 2,460 ft/s.

Photographs of unfilled and filled single-wall projectiles that failed are given in Figure 7. Photographs of unfilled projectiles of the three designs, cross sectioned after being fired at about 2,000 ft/s, are given in Figure 8. Similar photographs for filled projectiles fired at about 2,300 ft/s are given in Figure 9. The projectiles shown in Figures 9a and b had the filler removed before the pictures were taken. In Figure 9c the filler is still in place.

ANALYSIS OF PROJECTILE BEHAVIOR

Examination of the results of this study demonstrated the need to consider single- versus double-wall behavior, the location of the transition to double wall for the double-wall designs, and the presence or absence of explosive simulant filler. All these factors relate to the basic modes of failure observed in the test projectiles and, hence, to their survivability.

Several points can be noted from the bracketing values for survival velocity given in Table 2.

1. For either the filled or unfilled condition, double-wall projectiles had a higher survival velocity when the transition to double wall was at the 0.71-inch location.

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[4] Defense Nuclear Agency. *Projectile Penetration in Earth Material: Theory and Computer Analysis*, by R. S. Bernard and D. C. Creighton. Washington, D.C., DNA, November 1977. (Contract Report S-76-13, publication UNCLASSIFIED.)

TABLE 1. Summary of Test Results.

Projectile type	Mass, g	Impact velocity, in.	Penetration depth, in.	Diameter at nose, in.	Diameter at cavity bulge, in.	Length, in.	Sleeve displacement at rear, in.	Remarks
Single-wall, unfilled	20.02	2,015	3.0	0.503	0.534	1.967	...	Survived
	19.98	2,270	3.5	0.510	0.544	1.950	...	Survived
	19.94	2,440	3.7	0.515	0.623	1.905	...	Survived
	20.11	2,495	3.5	0.515	0.621	1.903	...	Survived
	19.86	2,550	2.8	0.518	...	...	...	Circumferential fracture, petalling
	19.73	2,580	2.7	0.521	...	...	...	Circumferential fracture, petalling
Double-wall, 0.46 inch from front, unfilled	19.84	1,635	2.1	0.500	0.536	1.976	0.180	Survived
	19.79	1,820	2.2	0.502	0.571	1.951	0.172	Survived
	19.83	1,930	2.4	0.504	0.599	1.905	0.117	Survived
	19.73	1,960	2.3	0.504	0.620	1.915	0.156	Survived
	19.90	2,015	2.2	0.507	...	...	...	Circumferential fracture, case forced into nose
	19.76	2,035	2.5	0.504	...	...	...	Circumferential fracture, case forced into nose
Double-wall, 0.71 inch from front, unfilled	19.85	2,050	2.6	0.505	0.557	1.952	0.482	Survived, bulged 0.71 inch from front
	19.85	2,165	3.5	0.506	0.602	1.898	0.436	Survived, bulged 0.71 inch from front
	19.78	2,285	3.3	0.509	0.623	1.872	0.406	Survived, bulged 0.71 inch from front
	19.74	2,290	3.5	0.508	...	...	...	Circumferential fracture
	19.74	2,320	3.3	0.501	...	...	...	Circumferential fracture
	19.62	2,475	3.6	0.513	...	...	...	Circumferential fracture
Single-wall, filled	26.08	2,280	3.5	0.509	0.645	1.885	...	Survived
	26.46	2,305	2.7	0.512	...	...	...	Circumferential fracture, longitudinal split
	26.50	2,360	4.4	0.512	0.610	1.907	...	Survived
	26 64	2,380	5.0	0.513	0.618	1.919	...	Survived
	26.50	2,410	4.4	0.512	0.645	1.883	...	Survived
	26.36	2,425	2.7	0.524	...	...	...	Longitudinal and circumferential fractures
Double-wall, 0.46 inch from front, filled	26.41	1,920	3.0	0.502	0.569	1.951	0.008	Survived
	26.42	2,120	3.0	0.507	0.634	1.878	0.016	Survived
	26.29	2,185	3.7	0.507	0.640	1.880	0.008	Survived
	26.31	2,230	4.4	0.508	0.628	1.896	0.008	Survived
	26.28	2,250	2.9	0.509	...	...	...	Circumferential fracture, longitudinal split
	26.21	2,270	4.3	0.507	0.646	1.873	0.008	Survived
Double-wall, 0.71 inch from front, filled	26.21	2,285	4.1	0.511	0.622	1.910	0.063	Survived
	26.32	2,330	4.3	0.508	0.604	1.917	0.008	Survived
	26.25	2,400	4.5	0.511	0.644	1.878	0.070	Survived
	26.28	2,460	4.5	0.514	0.619	1.885	0.078	Survived
	26.25	2,480	4.7	0.519	0.634	1.875	0.109	Survived
	26.32	2,520	3.5	0.515	...	...	...	Circumferential fracture, longitudinal split

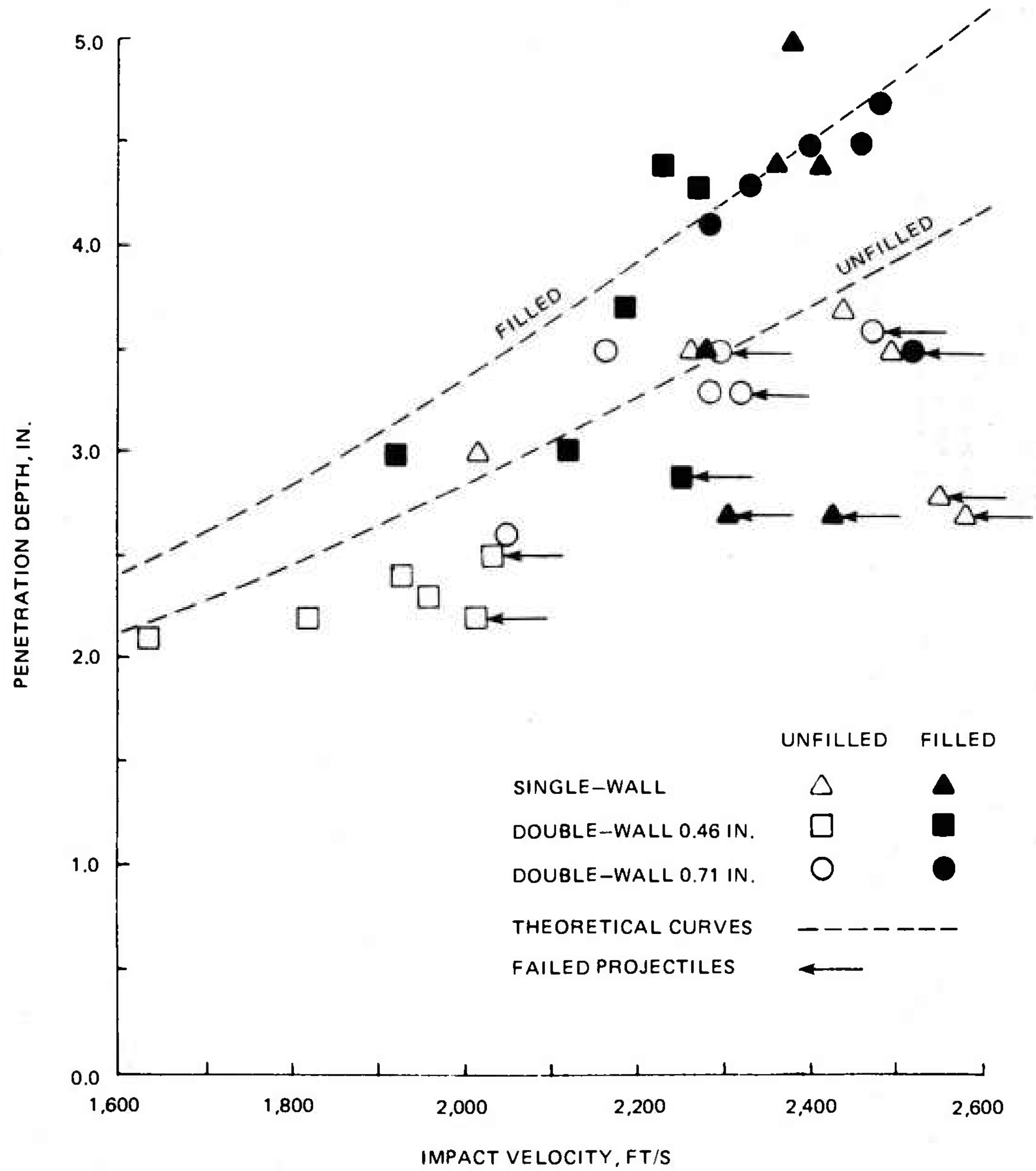


FIGURE 2. Penetration Depth vs. Impact Velocity.

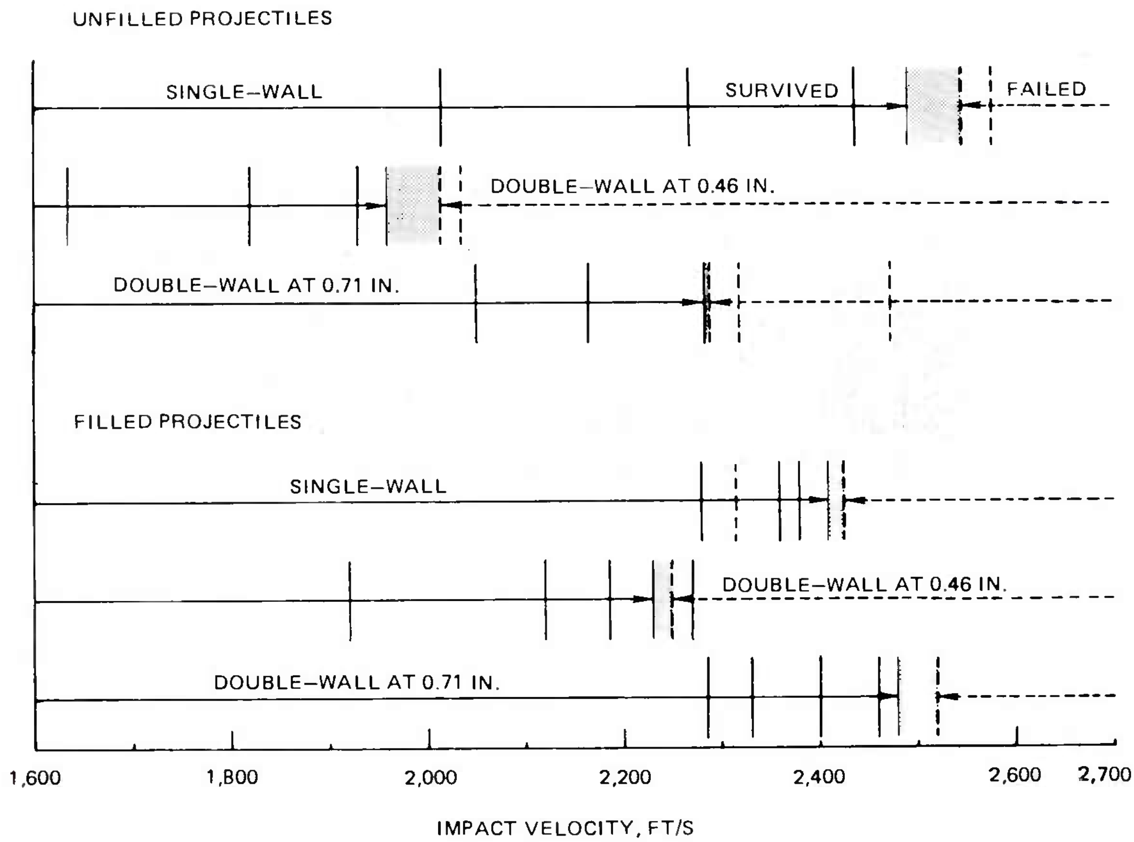


FIGURE 3. Impact Behavior of Filled and Unfilled Single-Wall and Double-Wall Projectile Designs.

TABLE 2. Bracketing Values for Survival Velocity.

Projectile design	Bracketing velocities, ft/s			
	Unfilled		Filled	
	Survived	Failed	Survived	Failed
Single wall	2,495	2,550	2,410	2,425
0.46-inch double wall	1,960	2,015	2,230	2,250
0.71-inch double wall	2,285	2,290	2,480	2,520

(a) Unfilled, 2,495 ft/s.

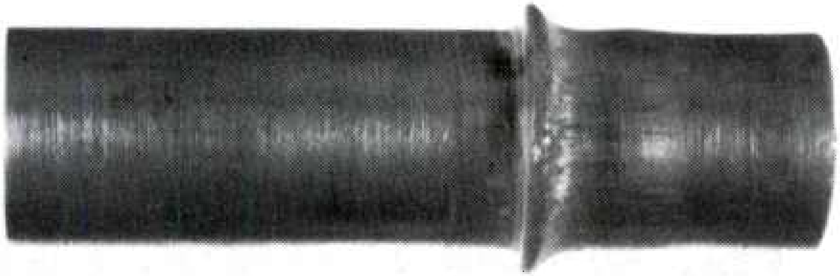
(b) Filled, 2,410 ft/s.

FIGURE 4. Photographs of Single-Wall Projectiles.

(a) Unfilled, 1,960 ft/s.

(b) Filled, 2,230 ft/s

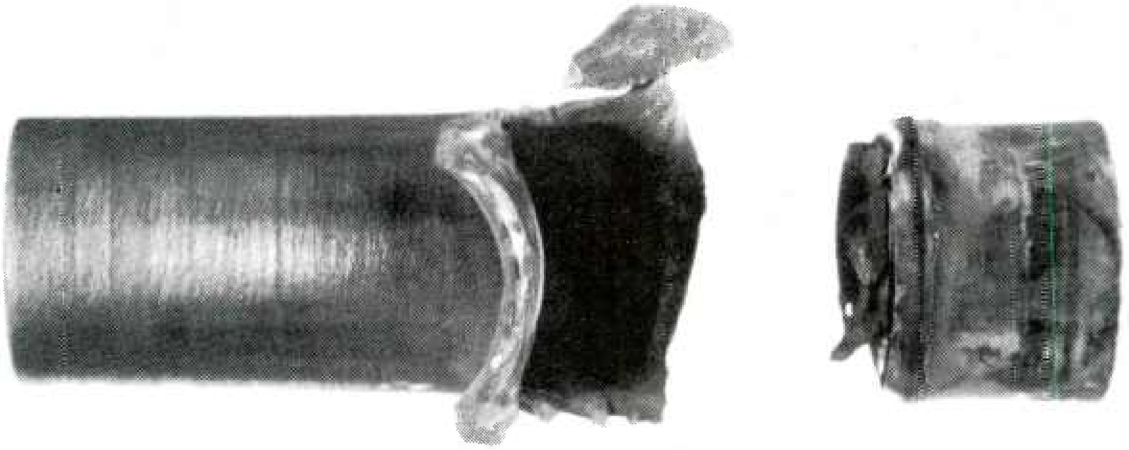
FIGURE 5. Photographs of Projectiles With Double Wall Starting 0.46 Inch From Front End.



(a) Unfilled, 2,285 ft/s.

(b) Filled, 2,460 ft/s.

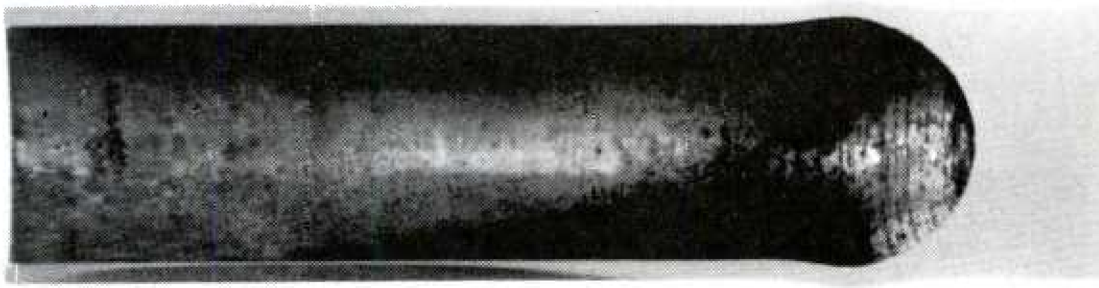
FIGURE 6. Photographs of Projectiles With Double Wall Starting 0.71 Inch From Front End.



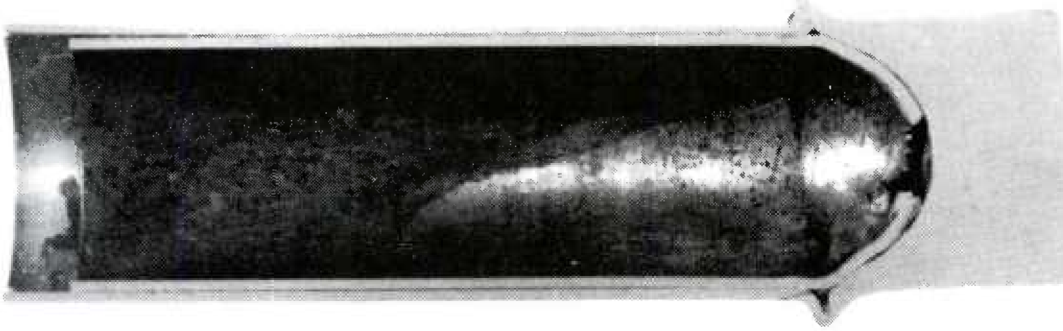
(a) Unfilled, 2,550 ft/s.

(b) Filled, 2,305 ft/s.

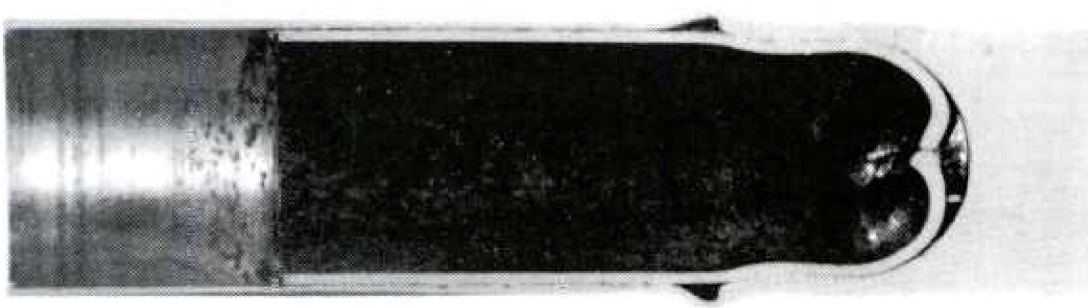
FIGURE 7. Photographs of Failed Single-Wall Projectiles.



(a) Single-wall, 2,015 ft/s.

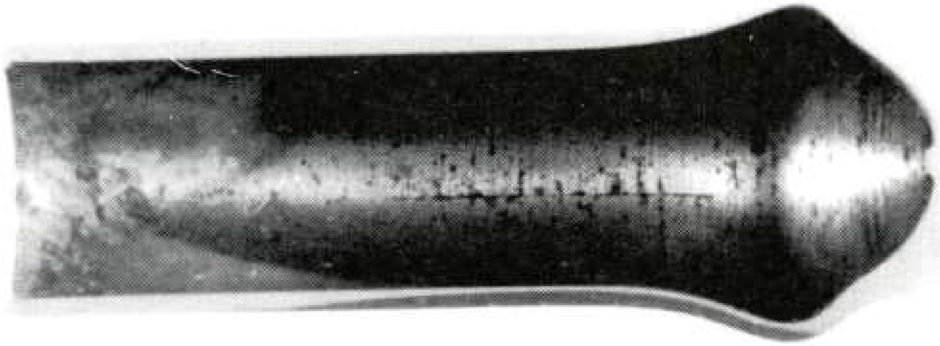


(b) Double-wall at 0.46 inch, 2,035 ft/s.

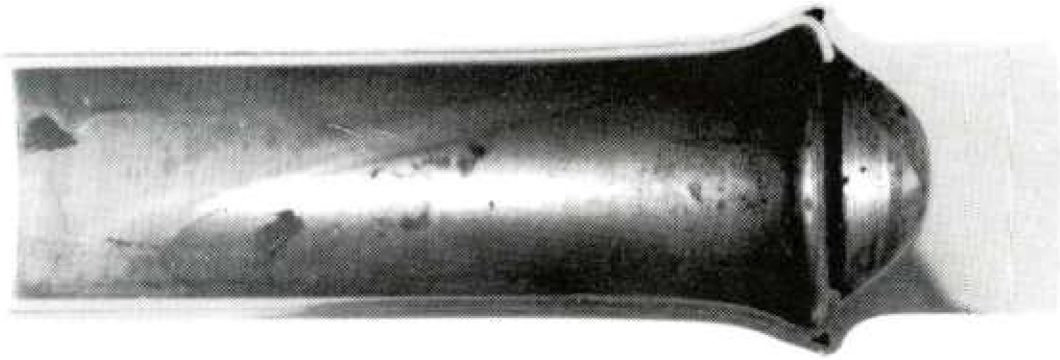


(c) Double-wall at 0.71 inch, 2,050 ft/s.

FIGURE 3. Photographs of Cross Sectioned Unfilled Projectiles.



(a) Single-wall, 2,280 ft/s.



(b) Double-wall at 0.46 inch, 2,270 ft/s.

(c) Double-wall at 0.71 inch, 2,330 ft/s.

FIGURE 9. Photographs of Cross Sectioned Filled Projectiles.

2. For the double-wall projectile, filled projectiles achieved a substantially higher survival velocity than unfilled projectiles of the same design.

3. For the unfilled projectiles, the single-wall design had a higher survival velocity than either of the double-wall designs.

4. For the filled projectiles, the 0.71-inch double-wall design behaved at least as well as the single-wall design.

SINGLE-WALL PROJECTILES

For both filled and unfilled projectiles, case deformation occurs primarily as a "bulging" centered at the transition from hemispherical front to constant thickness case wall (0.46 inch from the front end). For filled projectiles, the bulge region is quite wide, while for unfilled projectiles it is relatively narrow. This effect can be seen in the two projectile profiles in Figure 4. The height of the bulge (increase in radius) increases with velocity and finally terminates in circumferential shear fracture as shown in Figure 7a, which is a photograph of an unfilled single-wall projectile fired at 2,550 ft/s. Failure of filled, single-wall projectiles involved, in addition to circumferential fracturing, axial splitting of the case because of the hydrostatic pressure exerted by the filler. This effect can be seen in Figure 7b, which shows a filled single-wall projectile fired at 2,305 ft/s. For single-wall projectiles, the presence of filler reduced the survival velocity about 4%.

UNFILLED DOUBLE-WALL PROJECTILES

Major behavioral features of unfilled double-wall penetrators involved forward movement of the sleeve and the location of case failure.

For unfilled projectiles, the sleeve or liner does not appear to strengthen the case wall during the deformation process. Rather, the sleeve moves forward into the nose cavity independently of this process. If the impact velocity is sufficiently high, the nose cavity acts as a forming die and forces the metal from the forward end of the sleeve to conform to the hemispherical configuration of the cavity (Figures 8b and c). The projectiles were designed so that forward motion of the sleeve was restrained by a simple circumferential shoulder and the press-fit condition of the sleeve. This restraint was not adequate to prevent forward movement of the sleeve for the unfilled projectiles.

Both the 0.46- and the 0.71-inch designs failed by circumferential fracturing at the transition to double-wall. The 0.71-inch design achieved a substantially higher impact velocity before failure (about 14 to 17%) than did the 0.46-inch design. Potential locations for circumferential fracturing of the case wall are apparent in the cross-sectional views of Figures 8b and c and in the profile views of Figures 5a and 6a. (The 0.46-inch design in Figure 8b has already fractured although the projectile remained together after the test.)

FILLED DOUBLE-WALL PROJECTILES

Of all tests conducted, this group was most interesting in terms of the deformation and failure processes. Filled double-wall projectiles achieved higher survival velocities than did unfilled projectiles of the same design. These velocity increases were about 12 to 14% for the 0.46-inch design, and about 9 to 10% for the 0.71-inch design. This increase in survival velocity is attributed to the hydrostatic pressure exerted by the filler which helps hold the sleeve in place thereby strengthening the case.

For the 0.46-inch design, where the double-wall transition and single-wall bulge locations coincide, the deformation zone is quite narrow and the bulge sharply defined (Figures 5b and 9b). Failure initiates as a single circumferential fracture at the bulge. For the 0.71-inch design, where the double-wall transition lies to the rear of the primary bulge, the bulged region is considerably broader (Figures 6b and 9c). Failure can involve circumferential fracturing at either the primary bulge or the double-wall transition. (Circumferential fractures at both locations were observed in the one filled projectile of this design that failed.) Along with circumferential fracturing, axial splitting of the case can occur for any of the filled designs.

For both double-wall designs, the pressure exerted by the filler reduces forward movement of the sleeve and presses it outward into the bulged region, allowing it to act as a structural member during the deformation process, thereby strengthening the case and increasing projectile survival velocity. Differences in sleeve behavior for unfilled and filled projectiles can be seen by comparing Figures 8 and 9, while corresponding differences in case behavior for unfilled and filled projectiles can be seen by comparing Figures 5a and b and 6a and b.

CONCLUSIONS

The purpose of this experimental study was to examine the possibly deleterious effect of a double-wall case on the survivability of impacting warheads. The following conclusions can be drawn.

1. Double-wall case designs can be effectively used for penetrator weapons without reducing survival velocity provided that the double wall does not extend into the primary failure zone. If this zone is relatively small, the desirable fragmentation characteristics of the double wall can be maintained over the major portion of the case.

2. The hydrostatic pressure exerted by the explosive on the double wall keeps the inner wall pressed against the outer wall thus allowing the inner wall to act as a structural member during the deformation process. This contributes greatly to maintaining survival velocity.

3. Design consideration should be given to means of preventing forward motion of the inner wall during impact. The shoulder used in these experimental projectiles did not provide sufficient restraint.

4. Previous studies concerning the effects of shear-control grids on projectile survivability[1,2] indicate that shear-control grids could be employed on the double wall portion of the case to further enhance fragmentation. Such grids should not adversely effect survivability so long as the double wall itself does not extend into the primary failure zone.

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1 Tactical Fighter Weapons Center, Nellis Air Force Base (CC/CV)
2 57th Fighter Weapons Wing, Nellis Air Force Base
  FWW/DTE (1)
  FWW/DTO (1)
1 554th Combat Support Group, Nellis Air Force Base (OT)
1 Defense Nuclear Agency (Shock Physics Directorate)
12 Defense Technical Information Center
1 Department of Defense-Institute for Defense Analyses Management Office (DIMO) Alexandria,
1 Lewis Research Center, NASA, Cleveland
1 California Institute of Technology, Jet Propulsion Laboratory, Pasadena, CA (Technical Library)
2 Hercules Incorporated, Allegany Ballistics Laboratory, Cumberland, MD
1 IIT Research Institute, Chicago, IL (Department M, Document Librarian)
2 Johns Hopkins University, Applied Physics Laboratory, Laurel, MD (Document Library)
2 Johns Hopkins University, Applied Physics Laboratory, Chemical Propulsion Information Agency, Laurel, MD
1 Los Alamos National Laboratory, Los Alamos, NM (Reports Library)
1 Princeton University, Forrestal Campus Library, Princeton, NJ
1 Stanford Research Institute, Poulter Laboratories, Menlo Park, CA
1 The Rand Corporation, Santa Monica, CA (Technical Library)
1 University of California, Lawrence Livermore National Laboratory, Livermore, CA
1 University of Denver, Denver Research Institute, Denver, CO
1 University of South Florida, Tampa, FL (Department of Structures, Materials and Fluids, W. C. Carpenter)